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Final Technical Report
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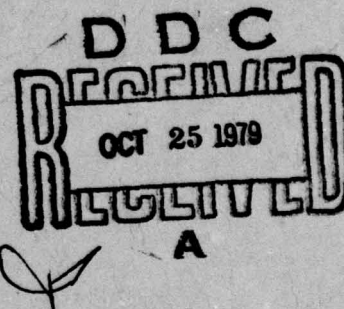# MILLIMETER RADAR SEA RETURN STUDY

by
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April 1979

Prepared for

The Dahlgren Laboratory
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A site selection process was performed for a planned field exercise to measure radar sea clutter reflectivity at low grazing angles using several radar frequencies between 9.5 and 95 GHz. A detailed test plan was developed to collect calibrated radar cross section data over a variety of geometric and environmental conditions. The data collection and calibration processes have been described using radar systems and ancillary electronic equipment.

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FOREWORD

This investigation was performed by personnel of the Radar and Instrumentation Laboratory of the Engineering Experiment Station at the Georgia Institute of Technology in Atlanta, Georgia. Dr. Robert N. Trebits served as the Project Director, with Ms. Margaret M. Horst as the Associate Project Director of this investigation, designated Georgia Tech Project A-2013. This program was sponsored by the Dahlgren Laboratory of the Naval Surface Weapons Center in Dahlgren, Virginia under Contract No. N60921-77-C-A168. Mr. John J. Teti (Code CF-14) served as Project Engineer for the Navy.

This Final Technical Report covers the work which was performed between February, 1978 and October, 1978. The author of this report is R. N. Trebits. The guidance provided by NSWC personnel was especially appreciated, with particular acknowledgment directed to John Teti, Ronald Stump, and Paul Leimer.

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ABSTRACT

The objectives of this phase of the program were to (1) perform a site selection analysis, (2) prepare and/or modify existing experiment grade radar systems, (3) prepare a detailed test plan, and (4) identify data collection/calibration procedures, all for a multifrequency, low angle, radar sea clutter, measurement exercise. The purpose for these measurements will be to increase the meager quantity of useful sea backscatter data which have been collected at millimeter wave frequencies.

Candidate sites for this measurement exercise included (1) the off-shore research towers at Panama City, Florida, operated by the Naval Coastal Systems Center; (2) San Nicolas Island, west of Point Mugu, California, operated by the Pacific Missile Test Center; (3) the Oceanographic Research Tower off-shore San Diego, California, operated by the Naval Oceanographic Systems Center; and (4) a field site at Boca Raton, Florida, operated by Georgia Tech. A fifth candidate site was also evaluated, San Nicolas Island with support by NOSC and PMTC. Each candidate site and support were evaluated in areas of facility attributes, instrumentation support, environmental conditions, data reduction support, and logistics. Accumulated weighted scores in each evaluation area were, in turn, summed to determine each candidate's net ranking. Based on these premises, the Stage II Research Tower at NCSC was selected for the radar sea clutter measurement exercise.

A detailed test plan was developed, which addressed site support requirements, personnel requirements, radar and ancillary equipment requirements, and data collection requirements. Basic low angle measurements to be included in this

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exercise are (1) normalized radar cross section (σ^0) data, (2) multipath interference data, and (3) propagation data, all recorded simultaneously at 9.5, 16, 35, and 95 GHz. Matrices for data collection were established for a variety of sea states, wind directions, and depression angles.

Analyses of the data collection/calibration process were performed. Both parallel- and cross-polarization data will be collected and calibrated, using a signal source and corner reflector procedures whenever possible. Consideration was also given to the types of data to be collected, both temporal, single range gated data and spatial, multi-range gated data for radar backscatter characterization.

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INTRODUCTION

1.1 Scope

The defense of a ship against aircraft and missiles flying very close to the sea surface has emerged as a major concern to the Navy. Tracking radars which are currently in the fleet operate in the microwave region at frequencies at or below 10 GHz, and these systems suffer degraded performance when attempting to track targets near grazing incidence. Phenomena which contribute to this degraded tracking performance include multipath interference effects, relatively poor radar system resolution, and false target returns called "sea spikes."[1]

It has long been conjectured that radar operation in the millimeter wave region of the spectrum could offer much improved tracking performance of low flying aircraft and missiles. The sea surface should appear "rougher" at these higher frequencies, and the multipath interference effects would be correspondingly less severe. Radar system resolution could be improved since, for the same aperture size, antenna beamwidths will be narrower for millimeter waves than at microwave frequencies. In addition there is evidence that the sea spike (false target) problem may be less intense in the millimeter wave region than at microwaves.[2]

Radar system performance historically has been mathematically modeled from data which are descriptive of the environment, the radar system, and the overall geometry. Unfortunately, the sea clutter data base at millimeter wave frequencies appropriate to the near grazing geometry is not extensive enough to accurately model for all pertinent parameters.[3-6] Thus, radar performance models which use these clutter inputs cannot confidently be relied on under all required conditions.

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The millimeter wave sea reflectivity investigation outlined in this report addressess this particular data base in the hope of providing sea clutter characterization at both microwave and millimeter wave frequencies under identical environmental and geometric conditions through simultaneous measurements.

1.2 Objectives

A major objective of these sea clutter measurements will be to create a millimeter wave data base over a wide range of environmental conditions characteristic of open sea conditions. Sea backscatter measurements of the same resolution cell made simultaneously at several frequencies between 9.5 and 95 GHz will permit confident modeling of sea reflectivity well into the millimeter wave region, where some of the most intense radar hardware development is taking place. A more complete characterization of the sea clutter return in this frequency region will ultimately allow calculation of radar system performance which might be expected.

The simultaneity of sea clutter measurements will permit parametric characterization of the return signals for identical geometric and sea/air meteorological conditions as a function of radar frequency. Measurements at 9.5 GHz will ensure reference to the extensive data base which has been documented there, while those measurements at 16, 35 and 95 GHz will greatly expand the data base into the millimeter wave region. With this multifrequency, sea backscatter data base and subsequent mathematical characterization, the radar system analyst will no longer have to extrapolate from data recorded by multiple investigators at different locations with different radar parameters.

1.3 General Test Description

This measurement program addresses the collection of sea backscatter data at near grazing incidence to the sea suface at frequencies of 9.5, 16, 35, and 95 GHz. These measurements will be conducted from the Stage II Research Tower located approximately 3 kilometers offshore Panama City, Florida, which is operated by the Naval Coastal Systems Center. In addition to sea backscatter measurements at these frequencies, measurements will also be conducted of propagation, ducting, and multipath interference effects in the millimeter wave region.

Sea backscatter data will include noncoherent reflectivity (amplitude only) of the sea surface for both horizontal and vertical transmission polarizations, at each of the four indicated frequencies. For each transmitted polarization, both the parallel- and cross-polarization component of the radar cross section per unit area (σ^0) may be determined for HH, HV, VV, and VH polarization combinations. Simultaneous recording at all four frequencies will be conducted in order that the recorded data represent as near identical sea and environment conditions as can be obtained. Measuring the parallel- and cross-polarization components of the reflected signal for both horizontal and vertical transmissions will increase the confidence level of the backscatter data. Since HH and HV are measured simultaneously, as are VV and VH, and since HV and VH should be equal, the relationship between HH and VV will be more confidently determined.

Supplementary data at a single frequency and both received polarization components will also be collected with emphasis on spatial correlation over several contiguous range cells. Past data measurement programs have indicated that the amplitude distribution of the return signal is a function of the cell of resolution. If the cell is large enough, then the amplitudes follow a Rayleigh distribution. Many

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reports of log-normal distributions have also been reported. The experiment of changing the cell location will also afford the opportunity to change the cell of resolution and thus determine the relationship between spatial distributions and amplitude distributions.

Supportive environmental data will be documented alongside the received radar power data, including air temperature, wind direction/speed, wave height, barometric pressure, relative humidity, and water temperature. This information will be used to correlate environmental parameters with radar signal characteristics, where possible. This correlation will then be manifested in the sea clutter model as specific parametric dependencies, mathematically formulated.

The general procedure to be undertaken to determine σ^o and related statistical descriptors will be to record sampled radar video signals on FM tape from each of the separate radar systems. System transfer functions will then be determined using calibrated signal sources and appropriate attenuation. A cross check to this calibration procedure will be provided by recording the reflected signals off a reference corner reflector or flat plate of known radar cross section. If the system powers, gains, and losses have been accurately determined, the measured received signals from the reference reflector will match the calculated signals at a specified range. Inability to close the calibration in this manner will indicate radar system problems or non-standard propagation conditions. Where signal sources are unavailable or cannot be utilized, a corner calibration procedure alone will be used.

Supplementary data will also be recorded which emphasizes propagation conditions, especially ducting effects. This will be effected by monitoring the backscatter power from a corner reflector over a period of time starting before

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daybreak and extending past sundown on several days when ducting can be anticipated. Additional data will also be documented on multipath interference effects at various frequencies, by recording the power reflected from a corner reflector which is mounted on an airplane or helicopter. By flying the reflector at a specified height over the mean sea surface along a radial path toward the radar, the multipath effects can be determined.

SECTION 2

SITE SELECTION

The selection of a site for a multifrequency, radar sea clutter, measurement investigation was undertaken using a set of desired operating facilities and conditions. The weighted sum of grades assigned to each requirement resulted in the selection of the Stage II Research Tower off Panama City, Florida as the preferred location for these measurements. This section summarizes this ranking process, while describing each of the candidate field sites in some detail.

Four general locations were investigated as potential sites for a low angle radar sea clutter measurement exercise. These locations include Panama City, Florida; Boca Raton, Florida; San Nicolas Island, California; and San Diego, California. Each of these sites offered its own particular advantages and disadvantages for a measurement operation, and the intent of the site selection process was to quantify their relative merits.

2.1 Panama City, Florida

Two offshore tower facilities were investigated for the measurement program, Stage I and Stage II, 19.3 and 3.2 kilometers respectively from the shoreline, operated by the Naval Coastal Systems Center at Panama City, Florida. Early in the analysis process, Stage I was the preferred site because of the deeper water conditions. However, it was determined that Stage II would offer significant calibration advantages because of its proximity to shore-based towers, so that this Research Tower became the more applicable facility. For completeness both Stages will be described.

The Stage I Research Tower is located approximately southwest of Panama City Beach, Florida in about 32 meters of water. The outside working area measures about 32 meters square on a side, with one corner of the flat deck containing an enclosed equipment room, as shown in Figure 1. The deck below the flat deck contains a living area (mess, recreation room, sleeping area, and head), a machine shop, and a support area (generators and storage).

Tower instrumentation includes wind speed/direction, tide, and significant wave height, all telemetered to shore for documentation. Air temperature, relative humidy, and barametric pressure instrumentation could be easily provided. A wave staff array can be used to determine wave vector information, if desired.

The significant advantages of Stage I are its "open sea" type of environment, variety of sea state conditions during the Fall, relatively unrestricted look directions, and meteorological and sea state instrumentation. The major disadvantage there is its logistic position far from shore equipment facilities and far from a hard calibration point on shore.

The site facility selected for this field operation is the Stage II Research Tower. This tower represents a site in reasonably open sea conditions, at least for wind directions out of the northwest to southwest (counterclockwise). The tower can be self-supporting logistically, a necessary condition, considering boat transit in the higher sea state conditions. A photograph of the Stage II Research Tower is shown in Figure 2.

Geographically the Stage II Research Tower is located at longitude 80° 40' 30" west and latitude 30° 7' 12" north almost due south of the Center. Figure 3 shows the location of the Stage II Tower with respect to NCSC and Panama City, Florida. Note that Stage II is located near four towers on the beach. The proximity of a
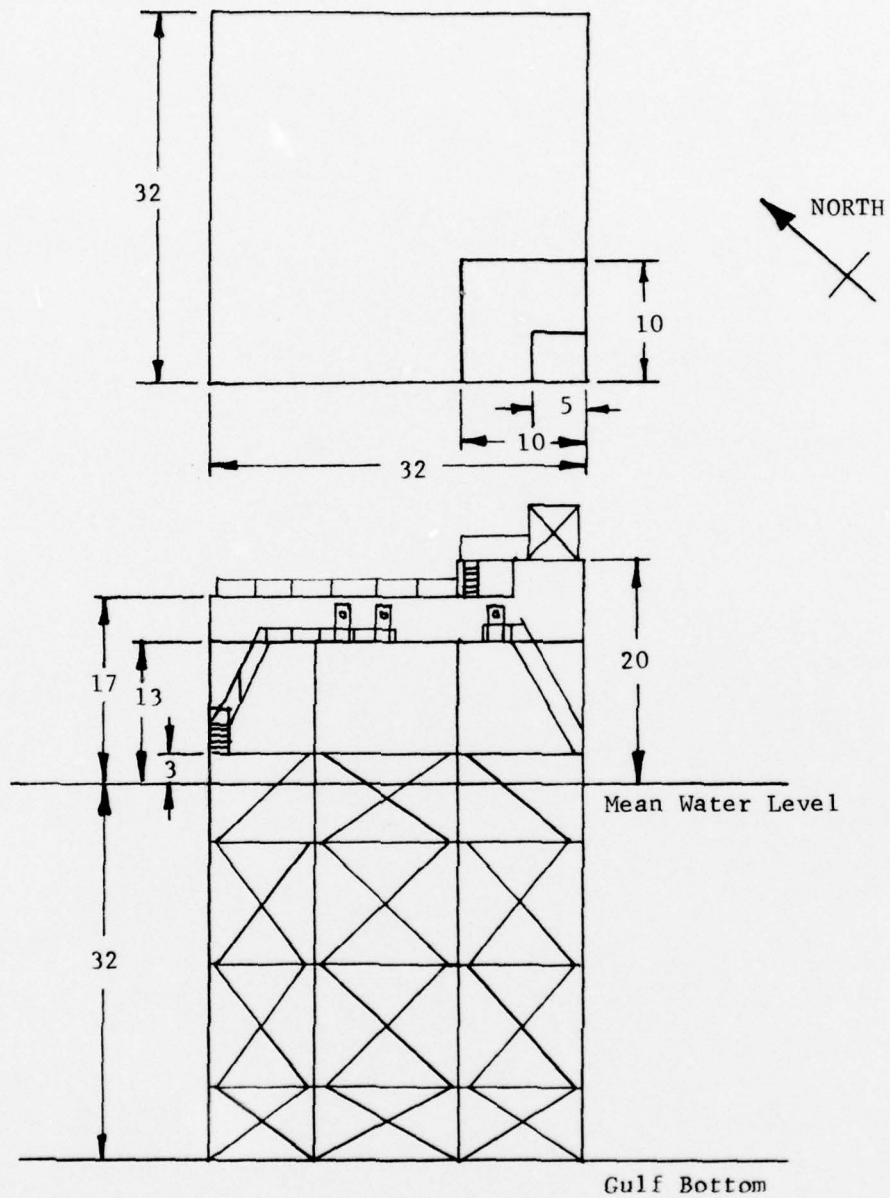
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Figure 1. Stage I Research Tower Facility (Dimensions in Meters).

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Figure 2. Stage II Research Tower Facility.

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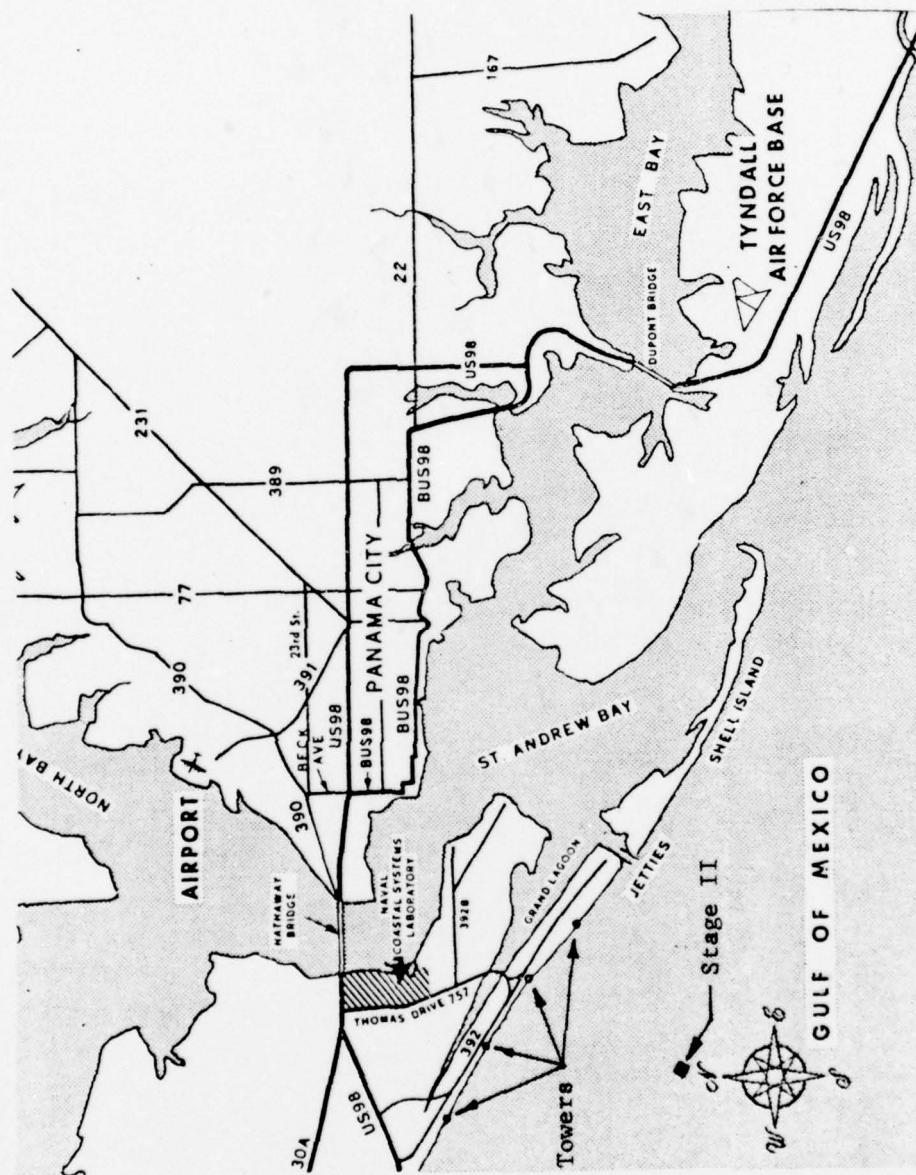
Figure 3. Locations of Stage II and Land Based Calibration Towers.

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land-based tower was the predominant rationale for the selection of the Stage II facility rather than the Stage I Research Tower. Land-based towers (see Figure 4) can be used to support the reflectors used to calibrate the reflected signal amplitude. These towers would not have been visible to all four radar systems on Stage I.

Physically Stage II is approximately 18 x 26 meters on the lowermost level (see Figure 5), which contains space for machinery, a galley, and fuel and water tanks. A second level measuring approximately 9 x 9 meters is located in one quarter of the tower and houses a repair shop. A third level measuring approximately 9 x 9 meters is located above the second level and houses an instrument room with bunk beds. A small flight deck is located above the third level. The roof of the first level is the proposed location for the radar systems. A boat landing is some 3 meters above MWL, and the three decks are 12, 15, and 18 meters above MWL. Figure 6 shows the orientation of Stage II with respect to North and to these towers.

The mean water depth surrounding the immediate vicinity of Stage II is some 20 meters, increasing gradually in distance from the shoreline to some 32 meters at the location of Stage I. The sea bottom is flat and sand covered, and is otherwise biologically and geographically featureless except in the area underneath the tower itself. The local diurnal tide range is 0.4 meters.

In the October to November time frame the air temperature in the Panama City area is in the range of 18-27 C (maximum) and 8-15 C (minimum). The average water temperature is within the range of 16-24 C for the same time frame. During this time period an average of five frontal passages per month through the Panama City area can be expected, and an average of three thunderstorms per month will occur. It might also be noted that within the Caribbean area the frequency of

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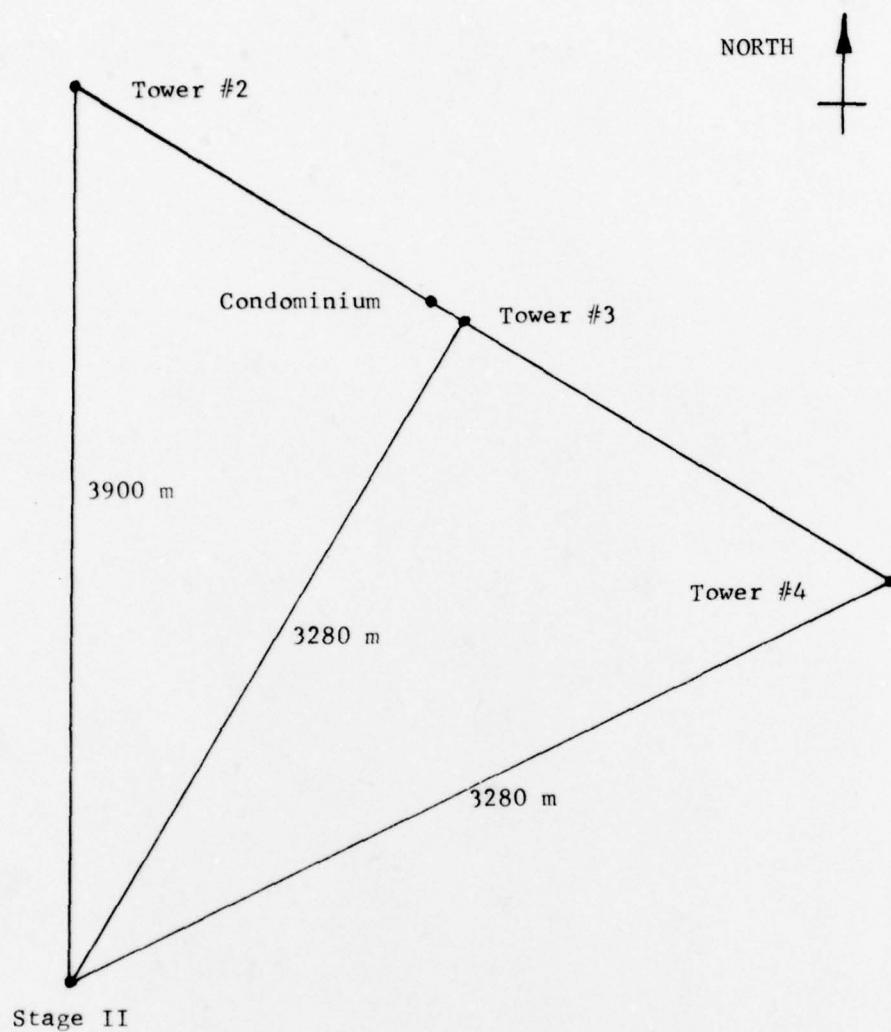
Figure 4. Positions of Towers #2, 3, and 4 and the Stage II Facility.

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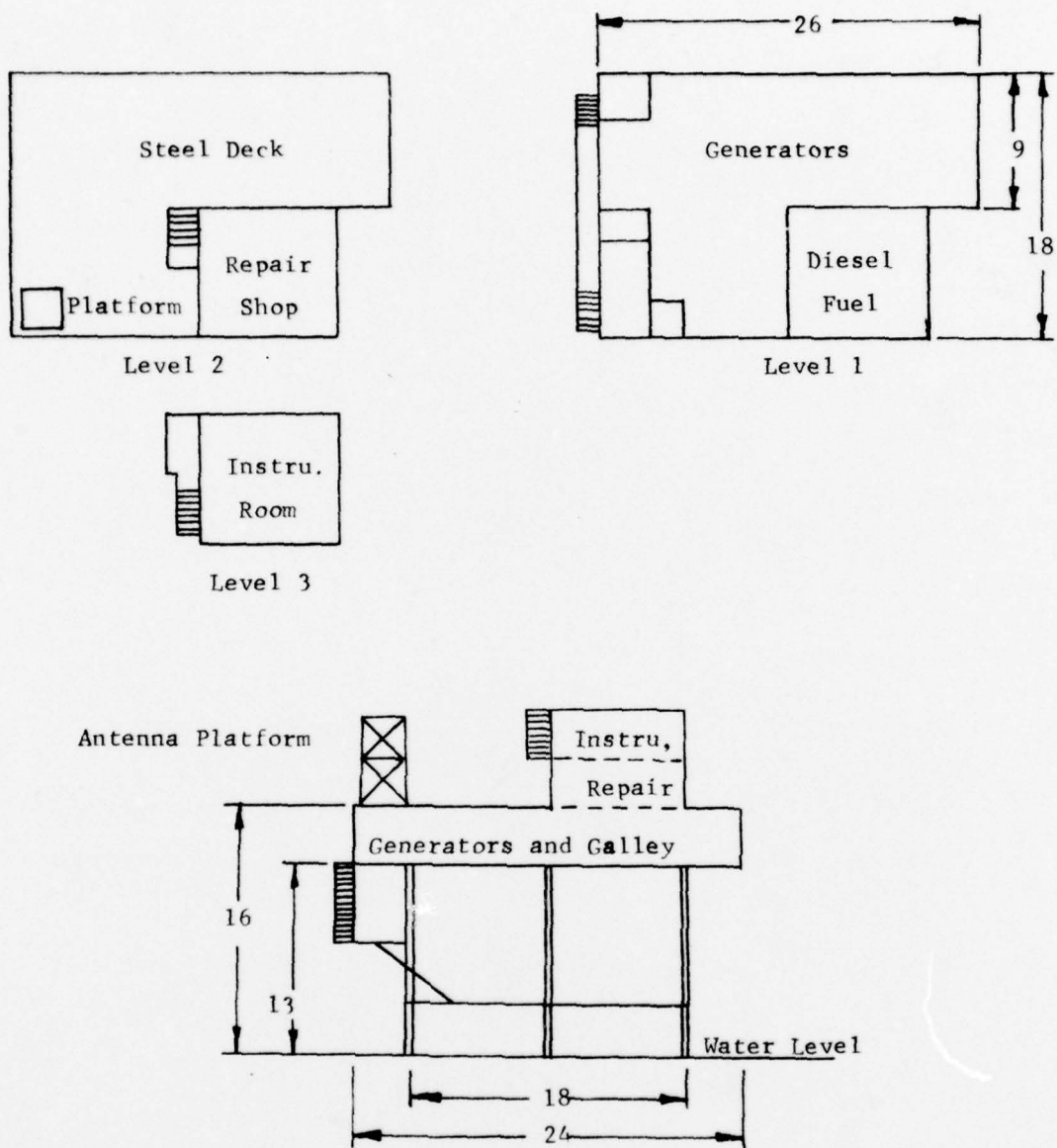
Figure 5. Stage II Research Tower Facility Layout (Dimensions in Meters).

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tropical storms during October and November is some thirty percent of the seasonal total. Sea state 1 conditions can be expected about 15 percent of the time, while sea states 2 and 3 will occur 40 and 30 percent of the time, respectively. Sea state conditions of higher wave heights than these will occur no more than 15 percent of the time.

The primary calibration site on shore is designated Tower #2 (see Figure 4) and is located 3,900 meters north of Stage II. This tower is constructed of reinforced concrete and is comprised of three observation levels, at 9.4, 11.7, and 13.7 meters above the mean water level. A concrete blockhouse outfitted for laboratory use sits below the tower and has telephone communications to NCSC. Tower #3 is virtually identical in construction to Tower #2 and is located at a closer range. However, a condominum is situated in the same range cell as Tower #3, while displaced azimuthally by only 150 meters. Thus, this building would be within 2.8 degrees of the bearing of Tower #3, which could create calibration errors.

An alternate calibration site is Tower #4, located 3,280 meters to the northeast. Tower #4 is a steel structure with a wooden deck estimated to be 8.5 meters above the mean water level. Both Tower #2 and Tower #4 are clearly visible from Stage II, as shown in Figure 6.

Stage II contains the same set of environmental sensors as Stage I. Transportation by boat to Stage II is somewhat easier than to Stage I because of the closer location and because wave height conditions tend to be less severe at Stage II than at Stage I. Alternate transportation by helicopter is available. The major advantage of Stage II is the presence of the calibration towers on shore without compromise of open sea conditions and a wide range of look directions. A

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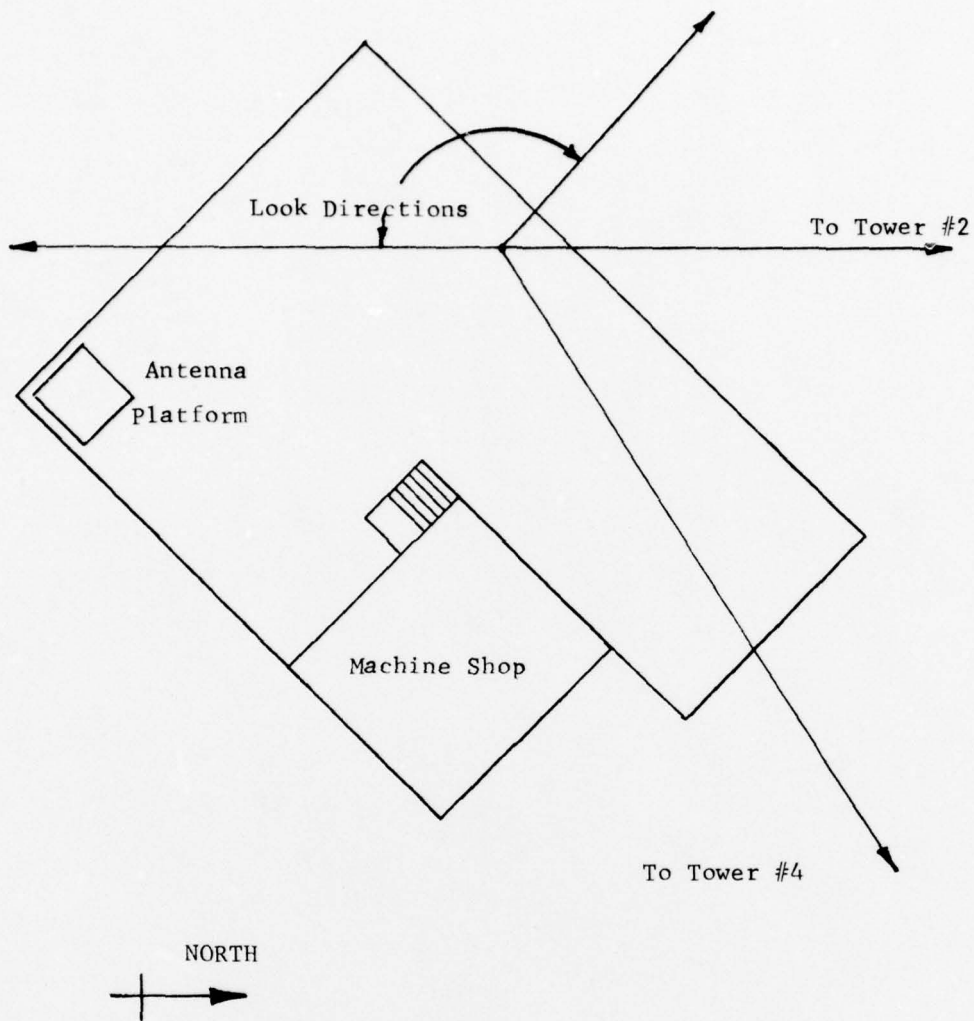
Figure 6. Orientation of the Stage II Deck Level and Lines-of-Sight to Calibration Points and the Gulf.

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disadvantage of Stage II is its less-than-ideal logistic position offshore and its poor living accommodations.

Additional support from NCSC can be obtained in the areas of office space, communication equipment, laboratory/repair shops on base, and stage-to-shore transportation. An NCSC-provided engineer also serves as cook on the Stages. Computer support is provided by the Range Data and Control (RADAC) facility, which performs the recording and reduction of environmental sensors on both Stages and can duplicate or digitize magnetic tapes.

2.2 Boca Raton, Florida

A field site, leased by the Navy and operated by Georgia Tech, at Boca Raton, Florida was briefly investigated as a candidate location for the sea clutter measurements. This site was situated on the oceanfront and was comprised of several air conditioned buildings, trailers, and a tower structure. The site had line power, telephone, and water facilities and was easily accessible from motels and restaurants.

Wavefronts move normal to the shoreline at Boca Raton, so that only a 90 degree sector centered on the upwind direction would have been available for pointing the radar antennas. Furthermore, no sea state or environmental sensors were available at the site and would have had to have been provided. No computer support was available for digitizing magnetic tape at the site.

Investigation of the Boca Raton site eventually became academic, since the property was sold for development during this program. For completeness the quantitative analysis, to be described in a later section, was also performed for the Boca Raton site.

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2.3 San Nicolas Island, California

San Nicolas Island, California is approximately 110 kilometers southwest of Los Angeles and is operated by the Pacific Missile Test Center at Point Mugu, California. Figure 7 shows the location of San Nicolas Island with respect to the California shoreline. The island is approximately 13 km long and 5 km wide, with the long dimension oriented northwest to southeast. The particular sites investigated are on the northwest tip of San Nicolas Island, as shown in Figure 8. An unrestricted view to the ocean is possible from northeast to due south, going counterclockwise. The wind and wave direction is usually from the northwest at 12-14 knots, so that both crosswinds, upwind, and almost downwind directions would be available. Sea state 3 conditions predominate year round.

The island has a workweek staff numbering 300 persons and has housing, transportation, food and recreational facilities for contractors. Air transportation to the island is scheduled every day to and from Point Mugu, and a barge landing provides a means of shipping heavy freight to the island.

Micrometerological instrumentation was scheduled to be installed in the spring of 1978 by the Naval Research Laboratory on a tower located near site A on the northwest tip of San Nicolas. Figure 9 shows this and several other relevent sites to be discussed. Additional environmental sensors are located at several nearby sites. However, sea state instrumentation is limited to two Datawell buoys off the northwest and west coasts of the island. It would be impracticle to install a wavestaff at any significant distance off the coast due to the rapid drop off of the sea bottom.

The candidate field site on San Nicolas is currently used by the Optical Signatures Program (OSP) and is designated OSP III site, as shown in Figure 9. This
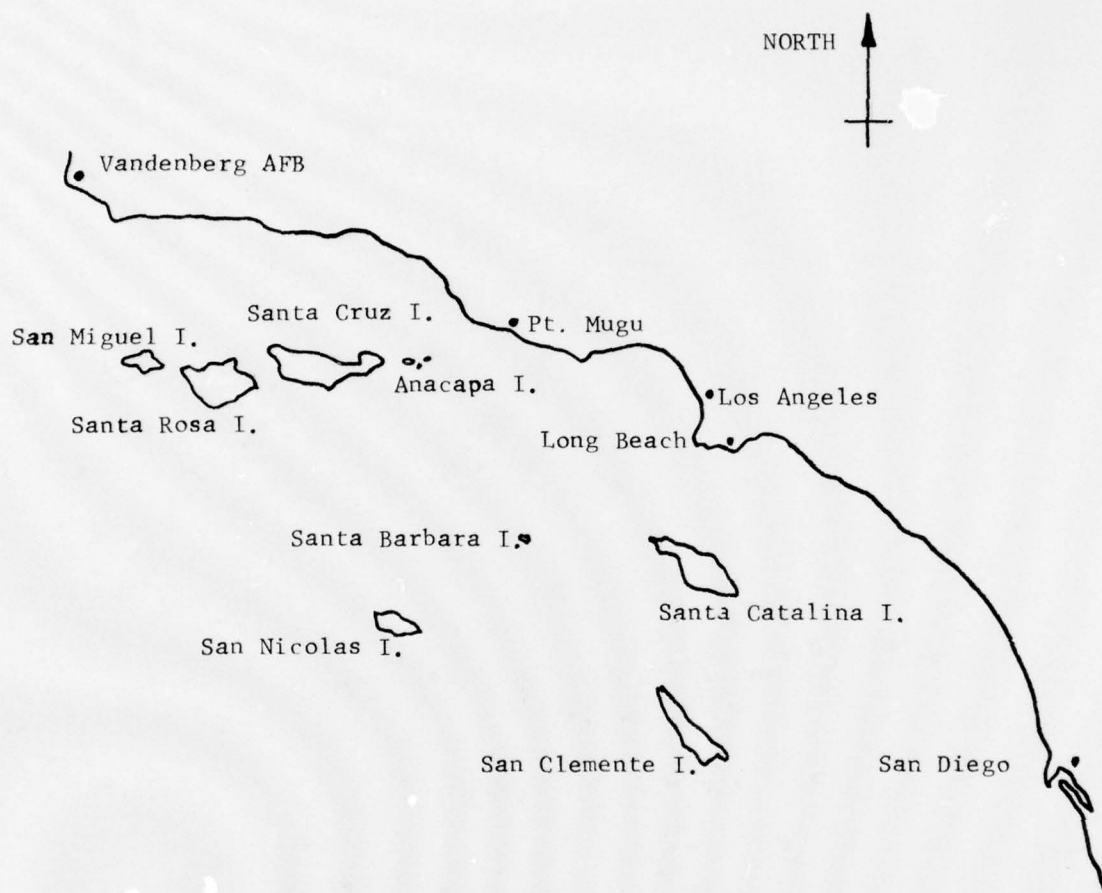
Figure 7. Southern California Coast and Offshore Islands.

NORTH

Site C

Site A

Site B

OSP III

Living
Area

Sea
Lion
Beach

Pier

Sea Elephant Beach

Barge
Landing
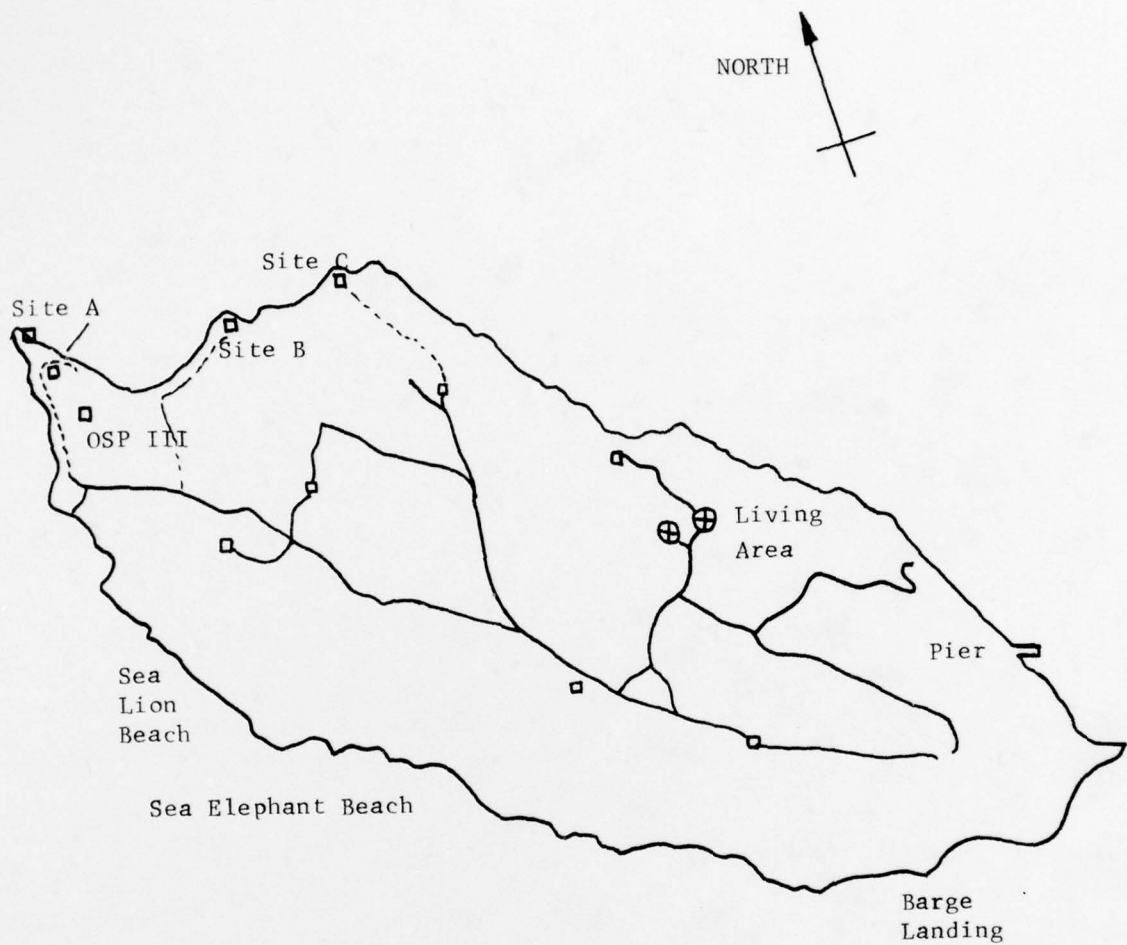
Figure 8.   San Nicolas Island Landmarks and Sites.

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NORTH

Wind

Site C

4 km

1.6 km

NRL Micromet
Installation

2.4 km

Site B

Site A

Calibration Site

OSP III Site

Northwest San Nicolas Island
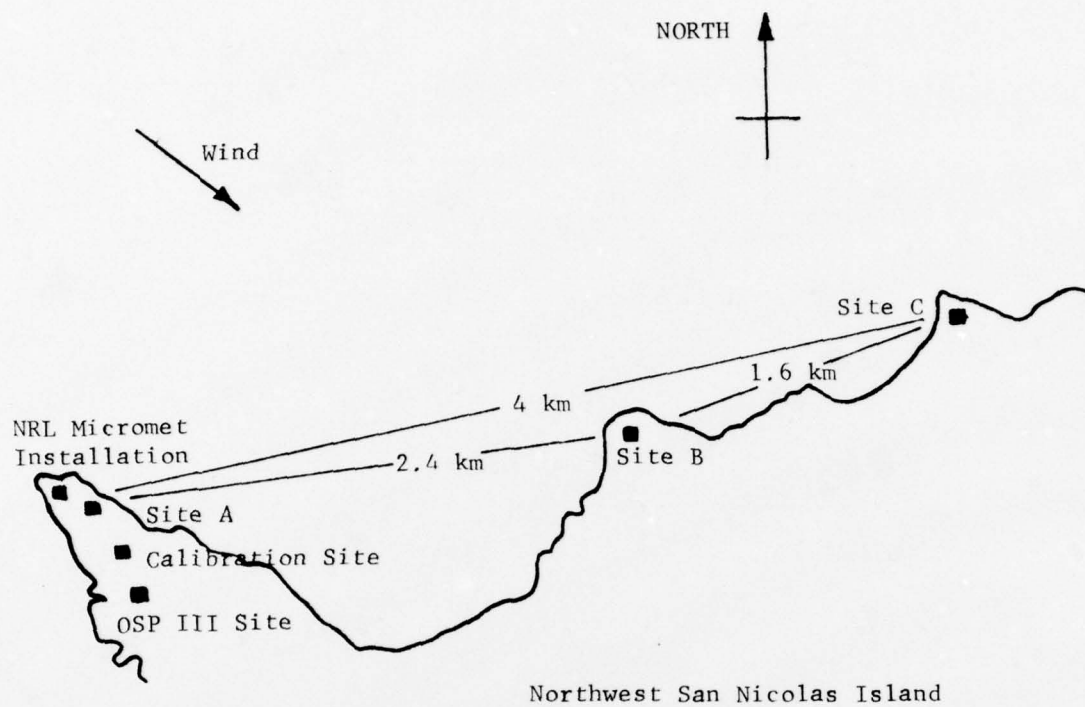
Figure 9. Optical Signatures Program Sites on San Nicolas Island.

site is some 45 meters above the mean water level and is scheduled to have on-site power and communication wiring. The prevailing wind is from the northwest so that both crosswinds and the upwind look direction can be obtained. The downwind direction would be somewhat restricted. While the orientation of the island presents a minimum cross section to the wind, the island land mass is expected to influence the wave fronts via reflections. Land influence, restricted wind direction, and constant sea state 3 conditions represent the major deficiencies of the San Nicolas site.

On the other hand, two land based calibration sites could be utilized from the OSP III site. Site B is located 2.4 kilometers away, and site C is 4 kilometers away, both over water paths and essentially in a line. These sites have power and communication facilities with each other and are easily accessible. The capability of performing a calibration to a land-based platform is the most significant advantage offered by the San Nicolas Island.

Some degree of electronic support can be obtained at PMTC or on San Nicolas itself, although it would be more feasible to seek assistance from NOSC in San Diego. There is little data reduction capability at PMTC, either in tape duplication or digitization.

2.4 San Diego, California

The candidate field site at San Diego, California is the Oceanographic Research Tower, operated by the Naval Oceanographic Systems Center (NOSC). The tower is 1.2 kilometers off Mission Beach in about 17 meters of water. The height of the platform on which the radar systems would be placed is approximately

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11 meters above the mean water level. Figure 10 depicts major structural details of the tower.

This tower was the sight of a measurement exercise performed by Georgia Tech during the summer of 1974. In fact, the same radar van was used during that exercise as is proposed in the present effort. One notable observation is that the operating space on this tower is especially restrictive, especially in terms of a crew of six persons or more.

The overall instrumentation on the tower, both above and below the surface, is extensive. Shore power is available on the tower, obviating the need for motor generators. While wind directions can be expected to vary, less than 180 degrees of look direction are possible, due to the geography of the shoreline. Furthermore, higher sea state conditions will make transit by boat impossible, with no practical alternative. Thus, being caught on the tower for several days at a time can be anticipated, in an extremely cramped environment incapable of supporting the crew required.

The computer, equipment, and logistic support available at NOSC is superior to that found at any other location investigated. However, the restricted work space and proximity to shore of the tower make this site less desirable. A compromise consideration was thus made of NOSC support at San Nicolas Island.

2.5   Site Evaluation Process

The purpose of the measurement program is to characterize the sea surface reflectivity at frequencies from 10 GHz through 100 GHz at grazing angles below ten degrees. To provide data meaningful to applications of the surface Navy, the measurements must be conducted in open water and in a "typical" sea environment.
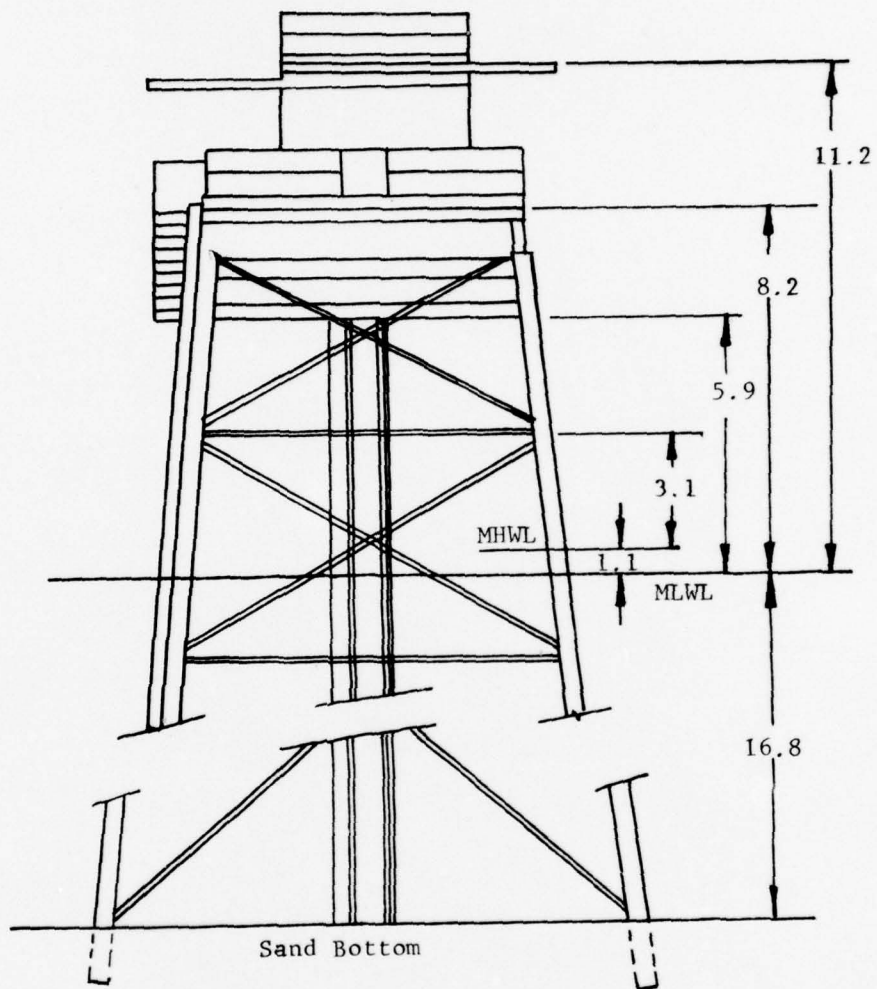
Figure 10. Oceanographic Research Tower at San Diego (Dim. in Meters).

Conclusions about the performance of a millimeter wave radar can then be obtained for operations at any location or any enviornment. This will be true only if: (1) the conditions at the chosen site are realistic of an open sea environment, and (2) there is significant variability in the environmental parameters which influence sea reflectivity. At the same time it is important to realize that in order to separate the effects of the individual parameters (i.e., wind speed and direction from wave height and direction), there must be low correlation between the parameters. Thus, wind speed and direction must change with respect to wave direction in order to seperate the effects of the wind and wave vectors. Table 1 lists the environmental requirements and their range of variability necessary to formulate a sea clutter model.

TABLE 1

DESIRED ENVIRONMENTAL VARIETY FOR SEA CLUTTER MODEL

Wave Height	0 to 4 meters
Wave Speed	0 to 30 knots
Wind Direction with Respect to Wave Direction	0 to 180 degrees
Look Direction with Respect to Wave or Wind Direction	0 to 180 degrees
Depression Angle or Grazing Angle	0 to 10 degrees

The variation in wave height and wind speed represents a range of sea state of 0 through 5 for fully developed seas and accounts for 80 percent of the expected seas at any time on a world-wide average. The two angular requirements of Table 1 are necessary to isolate the wind driven capillary waves from the "sea" or "swell" wave motion. The measurement of sea clutter, with respect to wind direction, will yield the parameters known as the upwind/downwind or upwind/crosswind ratios.

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The span of depression angles is necessary to discover the effect of radar frequency on the "critical angle" dependence of clutter return. The larger angles are necessary for the lowest frequency of concern, X-band (10 GHz) for this measurement.

Site parameters with desired values and range of values are given in Table 2. Each of the parameters of Table 2 can be divided into five categories: Facilities, Environment, Data Processing, Instrumentation, and Logistics. The actual parameters used in the evaluation process are given in Table 3.

At the conclusion of the site visits, an evaluation form (Table 3), was used to quantiatively score the four candidate sites and one combination of facilities. Each separate site parameter score was multiplied by a realistic weighting factor (between 0.1 and 1.0), which placed greater importance on those factors more critical to the program. The site parameters scores themselves were assigned according to the formula that a zero indicated impossible or impractical conditions, while a four indicated excellent capability. The weighted scores were then totaled for each site or combination of facilities.

Initial weightings and scorings were determined by both Georgia Tech and the Naval Surface Weapons Center. Results were compared, and where significant differences in judgements existed, a cooperative resolution was determined. Each reviewer maintained his own evaluation sheets, and no effort was made to make both identical. The evaluations of Georgia Tech and NSWC are summarized in Tables 4 and 5 respectively. Table 6 presents a composite of Georgia Tech and NSWC evaluations through averaging of both weighting factors and site parameter scores.

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TABLE 2

SITE REQUIREMENTS

1. Solid platform with radar height of 25 meters $\pm$ 5 meters.

2. Open sea conditions of at least 180° field of view and unobstructed in range to 20 km.

3. Sea state conditions such that sea states of at least 0 through 4 can be expected during a one month period.

4. Change of wind direction such that changes in sea clutter can be observed as wind drives smaller capillary waves in directions other than normal wave motion.

5. On site sea surface and meteorological instrumentation to measure: wave motion, direction, water temperature, air temperature, wind speed and direction, humidity, and atmospheric pressure.

6. Site large enough to accommodate the Georgia Tech van, additional instrumentation, and an operating crew of up to ten people.

7. Site must support the operations for a period of at least six weeks.

8. Long term (four hours) stable environmental conditions to allow for multiple measurements at constant conditions.

9. A far-field, rigid radar calibration point at least 2 km, and less than 10 km, from site.

10. Operations at night and during moderate sea state, fog, and high winds.

11. Sufficient and stable AC power to operate radar equipment.

12. Data processing capabilities to support the data reduction at or near site for "quick look" capability.

TABLE 3

SITE PARAMETERS USED IN THE EVALUATION PROCESS

Facilities

Platform Height Above Mean Sea Level
Platform Size
Look Direction
Movement After Set-Up to Afford Adequate Look Direction
Lab and Equipment Space
AC Power
Wash Down Water to Remove Salt Accumulations
Radar Calibration Point

Environment
Sea State Range
Wind-to-Wave Direction
Weather Down Time Due to High Wind or Heavy Rain
Water Depth
Salt Spray

Data Processing
A/D Conversion of 14 Channel Tape
Meteorological Data Reduction

Instrumentation
Basic Meteorological Instrumentation
Micro-Meteorological Data
Sea State Measurement
Lab Support for Repair and Calibration of Components
14-Channel Recorder Available at Site
Microwave Instrumentation for Test and Repair of Components.

Logistics
Supply Lines to East Coast, Delay in Shipment of Data or Parts
Meal Preparation
Lodging
Site Transportation
Communication To/From Site
Work Duty Factor
Night Operations to Observe Diurnal Effects
Movement of Van to Site
Aircraft Support to Provide a Measurement of Multipath Effects.

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TABLE 4

GEORGIA TECH SITE EVALUATION

Facilities	Weight	NCSL	SNI	NOSC	BOCA	SNI+ NOSC
Platform Height Above MSL	0.5	4	4	3	2	4
Platform Size	0.6	3	4	1	3	4
Look Direction	0.8	4	3	2	1	3
Movement After Set-Up	0.4	2	4	0	0	4
Lab. & Equipment Space	0.5	4	3	2	4	3
AC Power	0.3	3	4	4	4	4
Water	0.3	2	1	1	4	1
Radar Cal. Point	0.7	2	4	3	2	4
Subtotal		12.7	14.2	8.3	9.4	14.2
Environment						
Sea State Range	0.6	4	2	1	3	2
Wind-To-Wave Direction	0.8	4	3	2	1	3
Good Weather	0.6	3	4	4	3	4
Ocean Depth	0.7	4	4	3	4	4
Salt Spray	0.3	3	1	2	2	1
Subtotal		11.1	8.1	7.3	7.8	8.1
Data Processing						
A/D Conversion of 14 Chan. Tape	0.5	4	0	4	2	3
Met. Data Reduction	0.2	4	2	2	0	2
Subtotal		2.8	0.4	2.4	1.0	1.9
Instrumentation						
Basic Met. Instrumentation	0.8	4	4	4	1	4
Micro-Met. Data	0.5	2	4	3	0	4
Sea State Measurement	0.8	4	2	3	1	2
Lab. Support	0.4	3	2	4	1	3
14 Chan. Recorder	0.4	2	0	4	0	3
Microwave Instrumentation	0.4	0	2	4	1	3
Subtotal		9.4	8.4	11.9	2.4	10.4
Logistics						
Supply Lines To East Coast	0.2	2	1	3	4	1
Meal Preparation	0.3	1	3	3	4	3
Lodging	0.2	1	2	4	4	2
Daily Site Transportation	0.2	4	3	3	4	3
Communication To/From Site	0.4	3	2	2	4	2
Work Duty Factor	0.6	2	3	3	4	3
Night Operations	0.5	4	2	1	1	2
Movement of Equipment To Site	0.6	1	4	2	4	4
Aircraft Support	0.5	3	3	4	1	3
Subtotal		8.2	9.6	9.2	11.0	9.6
Total Score		44.2	41.7	39.1	31.6	45.2
% of Max. Score		75.7	71.4	67.0	54.1	77.4

TABLE 5

NAVAL SURFACE WEAPONS CENTER SITE EVALUATION

Facilities	Weight	NCSL	SNI	NOSC	BOCA	SNI+ NOSC
Platform Height Above MSL	0.5	4	4	2	1	4
Platform Size	0.5	3	4	1	2	4
Look Direction	0.7	4	3	2	1	3
Movement After Set-Up	0.3	3	3	0	0	3
Lab. & Equipment Space	0.5	3	2	1	3	2
AC Power	0.3	2	3	4	4	3
Water	0.3	3	1	2	4	1
Radar Cal. Point	0.7	2	4	3	2	4
Subtotal		11.6	12.0	7.3	7.5	12.0
Environment						
Sea State Range	0.7	4	2	1	3	2
Wind-To-Wave Direction	0.8	4	2	2	1	2
Good Weather	0.6	3	4	4	3	4
Ocean Depth	0.7	4	4	3	4	4
Salt Spray	0.3	3	1	2	2	1
Subtotal		11.5	8.5	7.4	8.1	8.5
Data Processing						
A/D Conversion of 14 Chan. Tape	0.6	4	0	4	2	3
Met. Data Reduction	0.3	4	3	2	0	3
Subtotal		3.6	0.9	3.0	1.2	2.7
Instrumentation						
Basic Met. Instrumentation	0.8	4	4	4	3	4
Micro-Met. Data	0.4	2	4	3	0	4
Sea State Measurement	0.8	4	1	3	0	2
Lab. Support	0.3	3	2	4	1	2
14 Chan. Recorder	0.4	2	0	4	0	3
Microwave Instrumentation	0.4	0	2	4	1	2
Subtotal		8.9	7.0	11.2	3.1	9.0
Logistics						
Supply Lines To East Coast	0.2	2	1	3	4	1
Meal Preparation	0.3	1	3	3	4	3
Lodging	0.2	1	2	4	4	2
Daily Site Transportation	0.2	4	3	3	4	3
Communication To/From Site	0.3	3	2	2	4	2
Work Duty Factor	0.5	2	3	3	4	3
Night Operations	0.3	4	2	2	0	2
Movement of Equipment To Site	0.6	1	4	2	4	4
Aircraft Support	0.4	3	3	3	1	3
Subtotal		6.6	8.4	8.0	9.6	8.4
Total Score		42.2	36.8	36.9	29.5	40.6
% of Max. Score		75.9	66.2	66.4	53.1	73.0

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TABLE 6

COMPOSITE SITE EVALUATION

Facilities	Weight	NCSL	SNI	NOSC	BOCA	SNI+ NOSC
Platform Height Above MSL	0.50	4.0	4.0	2.5	1.5	4.0
Platform Size	0.55	3.0	4.0	1.0	2.5	4.0
Look Direction	0.75	4.0	3.0	2.0	1.0	3.0
Movement After Set-Up	0.35	2.5	3.5	0.0	0.0	3.5
Lab. & Equipment Space	0.50	3.5	2.5	1.5	3.5	2.5
AC Power	0.30	2.5	3.5	4.0	4.0	3.5
Water	0.30	2.5	1.0	1.5	4.0	1.0
Radar Cal. Point	0.70	2.0	4.0	3.0	2.0	4.0
Subtotal		12.2	13.1	7.8	8.4	13.1
Environment						
Sea State Range	0.65	4.0	2.0	1.0	3.0	2.0
Wind-To-Wave Direction	0.80	4.0	2.5	2.0	1.0	2.5
Good Weather	0.60	3.0	4.0	4.0	3.0	4.0
Ocean Depth	0.70	4.0	4.0	3.0	4.0	4.0
Salt Spray	0.30	3.0	1.0	2.0	2.0	1.0
Subtotal		11.3	8.8	7.4	8.0	8.8
Data Processing						
A/D Conversion of 14 Chan. Tape	0.55	4.0	0.0	4.0	2.0	3.0
Met. Data Reduction	0.25	4.0	2.5	2.0	0.0	2.5
Subtotal		3.2	0.6	2.7	1.1	2.3
Instrumentation						
Basic Met. Instrumentation	0.80	4.0	4.0	4.0	2.0	4.0
Micro-Met. Data	0.45	2.0	4.0	3.0	0.0	4.0
Sea State Measurement	0.80	4.0	1.5	3.0	0.5	2.0
Lab. Support	0.35	3.0	2.0	4.0	1.0	2.5
14 Chan. Recorder	0.40	2.0	0.0	4.0	0.0	3.0
Microwave Instrumentation	0.40	0.0	2.0	4.0	1.0	2.5
Subtotal		9.1	7.7	11.6	2.8	9.7
Logistics						
Supply Lines To East Coast	0.20	2.0	1.0	3.0	4.0	1.0
Meal Preparation	0.30	1.0	3.0	3.0	4.0	3.0
Lodging	0.20	1.0	2.0	4.0	4.0	2.0
Daily Site Transportation	0.20	4.0	3.0	3.0	4.0	3.0
Communication To/From Site	0.35	3.0	2.0	2.0	4.0	2.0
Work Duty Factor	0.55	2.0	3.0	3.0	4.0	3.0
Night Operations	0.40	4.0	2.0	1.5	0.5	2.0
Movement of Equipment To Site	0.60	1.0	4.0	2.0	4.0	4.0
Aircraft Support	0.45	3.0	3.0	3.5	1.0	3.0
Subtotal		7.4	9.0	6.6	10.3	9.0
Total Score		43.2	39.2	38.0	30.5	42.8
% of Max. Score		75.8	68.8	66.7	53.5	75.1

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The conclusions of this site evaluation process was that both the Stage II Research Tower (NCSC, Panama City, Florida) and San Nicolas Island (PMTC, Point Mugu, California with NOSC instrumentation) could each satisfy the requirements of the sea reflectivity measurement program. Cost estimates from each facility to support the measurement program also impacted the ultimate site selection. The final site selection was made in favor of Stage II at Panama City, Florida.

SECTION 3

TEST PLAN

A test plan for a multifrequency, radar, sea clutter measurement program was generated which described (1) the measurement equipment, (2) the requirements for operation, and (3) the effectuation of the measurement exercises. This test plan was delivered to the Naval Surface Weapons Center and was approved as a technical guideline for the measurement program. This section summarizes the more significant features of the test plan.

3.1 Description of Measurement Equipment

The X-band (nominally 9.5 GHz) radar system associated with the Georgia Tech-owned Multifrequency Radar Test Facility will be used to provide the sea clutter data which will serve as a reference to the existent extensive data base at that frequency. Because of helicopter weight limitations, the enclosed rear portion of the van will be uncoupled from the truck body for transport onto the tower facility.

The X-band radar system, as noted in the parameter listing in Table 7, has an adjustable frequency of operation and an adjustable pulse repetition rate. The antenna to be used in these measurements is a steerable 1.5 meter paraboloidal dish with a dual mode coupler feed such that either horizontal or vertical polarization may be selected for transmission. For either transmitted polarization, both the parallel- and cross-polarization components of the backscattered power are received.

The X-band radar may be calibrated using a standard laboratory signal generator. An attenuator built into the signal generator allows the determination of

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Table 7

PARAMETERS OF X-BAND (GT-I) RADAR SYSTEM

Parameter	Value
Frequency	8.5 - 9.6 GHz
Peak Power	50 kWatts
Pulse Width	50 nanosecond
PRF	0 - 4000 pps
Antenna Type	Steerable, Nonscanning Paraboloid
Azimuth Beamwidth	1.5°
Elevation Beamwidth	1.65°
Antenna Gain	41.4 dB, Vertical Polarization
	41.6 dB, Horizontal Polarization
Polarization	H or V Transmitted, Selectable
	H or V Received, Simultaneous
IF Center Frequency	60 MHz
IF Bandwidth	20 MHz
IF Response	Logarithmic (Linear Available)
Noise Figure	12 dB
Dynamic Range	80 dB

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a system transfer function for both receiver channels. Amplitude measurements are then referenced to the return signal from a corner reflector of specified radar cross section and range so that receiver video levels may be correlated to radar cross section σ relative to a square meter. These calibration procedures are described in more detail later in this report.

The Ku-band (nominally 16 GHz) radar system to be utilized during this measurement effort is also associated with the Georgia Tech Multifrequency Radar Test Facility. The system parameters for this Ku-band radar are listed in Table 8. Note that the pulse width of 50 nsec is the same as that of the X-band radar previously described, and that with its 1.2 meter paraboloidal dish antenna, the Ku-band system also has a beamwidth comparable with the X-band radar. Both horizontal and vertical polarizations may be selected for transmission, and both parallel- and cross-polarization components of the reflected power are received simultaneously. The Ku-band radar can be calibrated with a signal generator feeding a calibrated signal into both receiver channels.

The Ka-band (nominally 35 GHz) radar system which will be utilized is a dual polarized (horizontal and vertical) system which is physically contained in an enclosure which can be mounted on a pedestal for steering the radar/antenna. The package has been designed so that either linear polarization may be transmitted by appropriate orientation of the mounting, while both of the relevant orthogonal polarization components are received simultaneously. Provision has been made for injection of a calibration signal into both receiver channels.

The pulse width and antenna beamwidths are roughly comparable to those of the X and Ku-band radar systems so that equivalent spot sizes can be used at

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Table 3

PARAMETERS OF Ku-BAND (GT-J) RADAR SYSTEM

Parameter	Value
Frequency	16 - 17 GHz
Peak Power	50 kWatts
Pulse Width	50 nanosecond
PRF	0 - 4000 pps
Antenna Type	Steerable, Scanning Paraboloid
Azimuth Beamwidth	1.5°
Elevation Beamwidth	1.5°
Antenna Gain	41.5 dB, Vertical Polarization
	41.4 dB, Horizontal Polarization
Polarization	H or V Transmitted, Selectable
	H or V Received, Simultaneous
IF Center Frequency	60 MHz
IF Bandwidth	20 MHz
IF Response	Logarithmic (Linear Available)
Noise Figure	13 dB
Dynamic Range	70 dB

identical ranges for all three systems. Other relevant parameters of the Ka-band radar system are listed in Table 9.

The 95 GHz radar system to be used on this measurement program utilizes an extended interaction oscillator (EIO) as a rf source, with a 1 kilowatt peak output power rating as described in Table 10. Due to this power limitation it will be necessary to use a 100 nsec pulse width for this system. Thus, the spot size at 95 GHz will be approximately 3 dB larger, thereby yielding a larger amount of reflected clutter power than possible with a 50 nanosecond pulse width.

Either horizontal or vertical polarization will be used on transmit, although the system is capable of transmitting left or right circular polarization. Transmission polarization is electronically controllable, rather than mechanically, between orthogonal polarization pairs, but for either mode both the horizontal and vertical polarization components are received simultaneously.

Additional instrumentation will be required to perform the measurement program outlined in this document. These items may be generally classified as pertaining to the data recording process, the environmental documentation, and the general support of the program. Specified items related to the facility support requirements or to the center support requirements will be addressed in a later section of this report.

The data documentation and recording systems required for this effort include FM magnetic tape and strip chart recording capabilities. Data generated by each radar system are to be sampled at the synchronized pulse repetition rate and stored on FM magnetic tape. Air and sea environmental parameters are also to be recorded, except that the more limited bandwidth requirements of these signals will permit their being stored on strip chart equipment. Synchronization of all four

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Table 9

PARAMETERS OF Ka-BAND RADAR SYSTEM

Parameter	Value
Frequency	34.5 - 35.2 GHz
Peak Power	40 kWatts
Pulse Width	50 nanosecond
PRF	0 - 4000 pps
Antenna Type	Steerable, Scanning Paraboloid
Azimuth Beamwidth	1.0°
Elevation Beamwidth	1.0°
Antenna Gain	43.0 dB
Polarization, Transmit	H or V, Selectable Geometrically
Polarization, Receive	H or V, Simultaneous
IF Center Frequency	60 MHz
IF Bandwidth	20 MHz
IF Response	Logarithmic (Linear Available)
Noise Figure	14 dB
Dynamic Range	70 dB

Table 10

PARAMETERS OF 95 GHz RADAR SYSTEM

Parameter	Value
Frequency	94.5 - 95.5 GHz
Peak Power	1 kWatt
Pulse Width	50, 100 nanosecond
PRF	1 - 10 kpps
Antenna Type	Steerable, Nonscanning Cassegrain Paraboloid
Antenna Beamwidth	0.7°, azimuth and elevation
Antenna Gain	47.1 dB
Polarization, Transmit	H or V, RC or LC, Selectable
Polarization, Receive	H and V, Simultaneous
IF Center Frequency	300 MHz or 60 MHz
IF Bandwidth	140 MHz or 20 MHz
IF Response	Logarithmic
Noise Figure	12 dB
Dynamic Range	60 dB

radar systems is to be provided by a master clock, which will also be used to trigger the sampling circuits. A time code generator and audio annotation will also be recorded on FM tape for later data reduction. Figure 11 depicts an overall system block diagram of the radars and support equipment to be employed. Note that there are two video lines for each radar system, the cross and parallel polarization components of the received sea clutter signal, resulting in a total of eight video signals plus a synchronization signal and a time code signal, for a final total of ten video signals. Eight of these ten, corresponding to the eight radar signals, are shown played out on strip chart recorders off the playback heads of the FM tape recorder to verify the magnetic recording and to check for deviations in the data signals themselves.

Meteorological parameters to be recorded include air temperature, wind direction, wind speed, barometric pressure, relative humidity, sea temperature, wave height, and wave direction. The first six of these environmental parameters may be recorded on strip charts, since all are low bandwidth type signals. Wave information from an array of four wave staffs on Stage II is already measured and transmitted to shore, althought it may be intercepted on the tower if monitoring is desired. On-base computation can be performed on the array data to yield wave front direction.

3.2 Requirements for Operation

Specific site requirements for Stage II include needs for power, operating area, living accommodations, and transportation. The latter two subjects are required because of the remoteness of the site from land and the inconvenience of daily
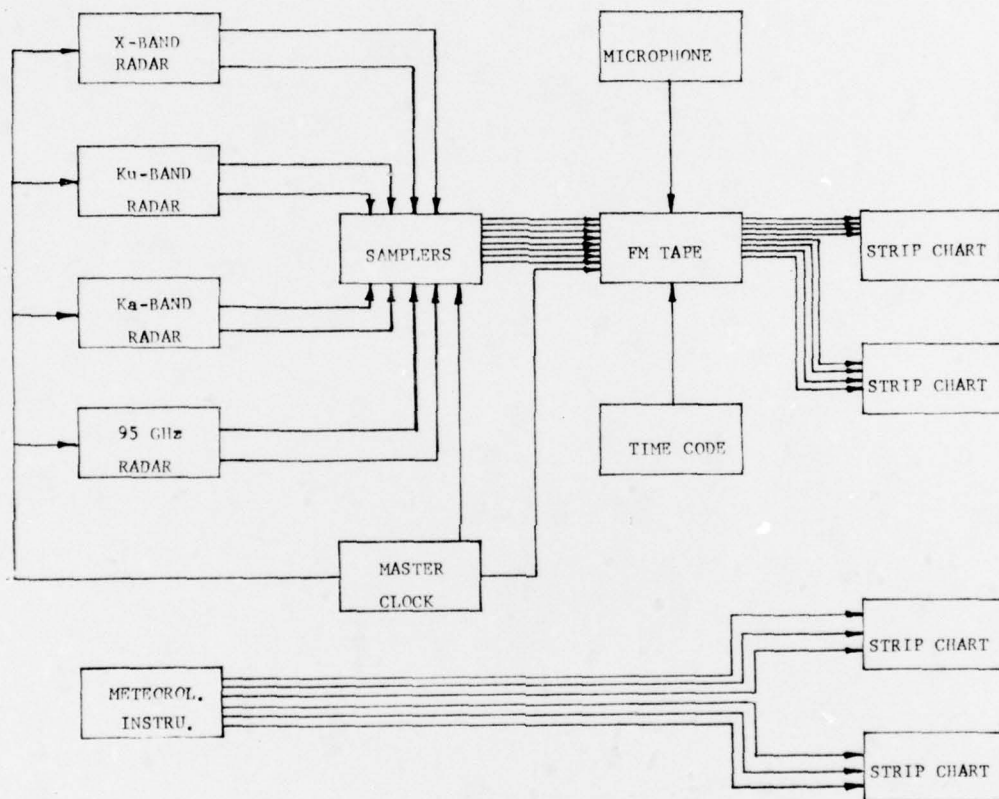
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Figure 11 Ancillary System Block Diagram Interfaced with Radars.

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travel to and from the Tower. In fact, boat travel to the Tower is not recommended for wave heights in excess of 3/4 meter.

Power required by electronic equipment to be placed on Stage II is conventional: 60 Hz, single phase, 230 volts, 20 kilowatts. The major load will be air conditioning for the van compartment which houses two of the radar systems and some support equipment. Additional power is required for operation of specific units of two of the radar systems: 400 Hz, three phase (Y configuration), 115 volts, 100 watts. These power needs are designated above whatever power requirements are dictated by operation of the Tower itself with all of its support gear operating.

Operating area needs include deck space on the first level roof (second level floor) for positioning of the van compartment, pedestal-mounted radar systems and several other pieces of electronic apparatus. Space inside a laboratory area is needed near the deck space position for placement of recording and monitoring equipment. Power outlets must be available in this laboratory area for the electronic equipment.

Living accommodations for at least eight persons for periods up to a week's duration will be necessary because of the remoteness of the Tower. Associated requirements will include sleeping quarters, food preparation and storage facilities, and toilet/bathing facilities.

The support required for this field measurement exercise from the Naval Coastal Systems Center includes manpower needs, hardware needs, facility needs, and transportation needs. Manpower requirements include a representative of the Center on Stage II at all times that Georgia Tech or NSWC personnel occupy that facility. This particular requirement will be described in more detail in a later section of the test plan. Additional Center personnel will be needed for the

transportation of equipment and personnel from the Center to the Stage II facility. It is anticipated that a helicopter and attendant crew will be used to transport the enclosed radar systems and other containers of electronic gear, food, and personal effects. A small boat will be necessary to ferry men back and forth to the Tower when sea conditions permit. Otherwise, when necessity dictates it, a helicopter must be available for transportation. A helicopter will also be used for multipath measurements during various times throughout the measurement period.

Additional mainland support will include availability of various electronic equipment, such as oscilloscopes, multimeters, etc., as required. Use of a calibration and repair shop will also be required during the duration of these measurements. It will be desirable that office space be made available on the Center for shore work by Georgia Tech and NSWC personnel. Identification badges for long-term personnel and vehicle passes should be acquired to minimize unnecessary paperwork.

It is the intention that FM magnetic tape be digitized at the NCSC Range Data and Control Center (RADAC). These tapes will be standard one-inch magnetic tape with multiple channels and will require multiplexed digitization onto 9-track tape compatible with a CYBER 74 computing system.

Radio communication using UHF or VHF transceivers will be required during this test operation. Georgia Tech is licensed to operate VHF transceiver base and remote units at frequencies of 151.625 and 151.475 MHz, so that permission to use these units is requested for the duration of these measurements. If preferred by NCSC, Center-licensed units can be operated instead from Stage II-to-shore and on Stage II itself, if provided by the Center.

It is understood that an NCSC engineer will be assigned to the Stage II Tower whenever field operations are underway there. This engineer shall be responsible for upkeep of the Stage II support systems, such as power, communications, water, fuel, et cetera. It is also understood that this engineer will serve as a cook for the crew which resides on the Tower overnight.

A small boat crew will be available for transportation of personnel and light equipment to the Tower as required during the duration of this exercise. This boat will be large enough to transport up to eight persons in addition to its normal crew.

Helicopter crews for the set-up process and the multipath measurements may be the same if only one helicopter is to be utilized for both operations. Otherwise, a crew for a smaller helicopter will be required for the multipath measurements.

Base manpower support shall be supplied at the computing facility RADAC in terms of persons necessary to digitize multi-channel FM magnetic tape and duplicate the digitized version. Additional manpower may be required to provide the environmental data reduction. Support is also desired for general repair of laboratory electronic equipment where feasible and calibration of same. Some amount of shop time may be necessary to fabricate structures as necessary.

The Naval Surface Weapons Center will maintain an engineer on the Stage II facility during the entire measurement exercise to assist in the data collection, provide guidance in meeting Navy needs, and assist in the overall planning of the day-by-day operations. An additional NSWC person is desired for base duty to interface with the computer/data processing center, represent NSWC and Georgia Tech to NCSC, coordinate tasks and assignments with NCSC personnel, and direct base area efforts in support of this measurement operation.

3.3. Effectuation of Measurement Operation

Because of the variety of sea state conditions which are available in the Panama City, Florida area during the Fall of the year, the October to November time frame has been selected for this measurement exercise. The amount of time estimated for this operation is eight weeks, including approximately two weeks for set-up/down. Thus, there will be a total of some six weeks to actually perform the various measurements which constitute the objectives of this program.

The designated equipment from Georgia Tech and the Naval Surface Weapons Center will be shipped from their respective locations so that transport can be effected onto Stage II from the Naval Coastal Systems Center at Panama City, Florida beginning 2 October 1978. The estimated time schedule ends 24 November 1978, by which date all equipment will have been transported from Stage II to Georgia Tech, NSWC, and NCSC. This is an eight week time period inclusive, with approximately six weeks of actual data collection and experiments available.

Transportation of most of the electronic equipment required for this program to Stage II will be undertaken by an RH-53 helicopter, which is understood to be load-limited at 12,000 pounds (5,455 kilograms). The major component to be so transported is a van compartment housing two radar systems, which weighs approximately 9,000 pounds (4,090 kilograms). Additional gear will be air towed by helicopter on pallets or other available containers to be supplied by NCSC. Unless circumstances demand it, personal transportation to and from Stage II will be by Navy boat, to be supplied with crew by NCSC.

The experimental tasks to be performed on this operation can logistically be grouped into three areas: sea backscatter measurements, multipath interference measurements, and propagation measurements. No order of experimentation is

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implied, and indeed, the order of data collection will be dictated by the task matrix overall test priorities, and weather constraints. Thus, reoccurrence of weather conditions will permit collecting data of the next experimental task in the priority list. These priorities will be in this order: sea backscatter, multipath interference, and propagation effects.

The sea backscatter measurements will have the highest priority and will be the predominant task performed during the six week period. The daily procedure to be followed will include a precalibration of the radar systems, data collection, and a postcalibration. Comparison of both calibration results will indicate some measure of confidence in the radar systems, especially when comparison is made to previous days' calibrations. The specific calibration procedure and data collection procedures will be described in a later section of this report.

The multipath interference measurements have the next highest priority after the sea backscatter measurements. After a precalibration, data will be collected by illuminating a corner reflector on a helicopter with several radar systems and recording the backscattered energy as the helicopter makes radial passes toward the tower at a specified altitude. The characteristic periodic constructive and destructive interference phenomenon may then be compared to calculated values. Tracking of the helicopter will be accomplished manually.

Propagation measurements will be effected by illuminating a corner reflector or flat plate mounted on a shore-based tower and monitoring the backscattered energy from before sun-up to after sundown in order to observe the diurnal changes of duct emergence and recession. As in the other tasks, this set of measurements will be done simultaneously at four separate radar frequencies.

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Table 11 lists a matrix of radar system, environmental, and geometric parameters which will be varied during the measurement exercise to characterize sea backscatter. It is the intent of listing this rather extensive matrix that it serve as a guide for the actual data collection process. Thus, as the measurement program progresses, the matrix elements may be altered via change, addition, and deletion as conditions and/or objectives evolve. The matrix obviously represents an optimistic viewpoint that all desired environmental conditions will be available during the time allocated and that these conditions occur in a most convenient order. Nonetheless, the matrix represents a guideline for daily measurement assignments.

Primary emphasis will be given to data representing radar beam orientations which are crosswind, upwind, and downwind where a stationary condition exists for the sea driven by a constant wind, i.e., a fully arisen sea. Additional sea backscatter data will be recorded for sea conditions which are in a state of change due to wind shifts, so that wave fronts and wind conditions are not yet correlated.

Depression angles from 3° down to 0.1° will be used for these measurements where system performance permits it. These data will permit determination of critical angle dependency in the millimeter wave region.

As stated previously, four radar systems will be operated simultaneously at 9.5, 16, 35, and 95 GHz. Both horizontal or vertical polarization will be transmitted, and both linear polarizations will be received simultaneously for either mode of transmission. These data will yield the amplitude dependencies of all components of the sea scattering matrix, at all four frequencies.

Primary sea backscatter data will include the parallel- and cross-polarization components of the received radar signal for four different radar bands. These data

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Table 11

SEA BACKSCATTER MEASUREMENT MATRIX

Environmental Parameters

    Sea State (Douglas)   0, 1, 2, 3

    Wavefront Direction
        Fully Arisen Sea   Upwind, Crosswind, Downwind
        Nonstationary Sea   As Available

Geometric Parameter

    Depression Angle $3°$, $1.5°$, $1°$, $.75°$, $.5°$, $.4°$, $.3°$, $.2°$, $.1°$

Radar Parameters

    Frequency   9.5, 16, 35, 95 GHz

    Polarization
        Transmitted   Horizontal or Vertical
        Received   Horizontal and Vertical

Data Parameters

    Temporal Dependence   1 Range Cell, Parallel and Cross

    Spatial Dependence   3 Contiguous Range Cells, Parallel

will allow calculation of mean radar cross section, amplitude distribution, power spectral density, and correlation properties of the sea backscatter energy. Obviously, since the recorded data are sampled from a single range cell every interpulse period, these descriptive statistical properties will represent time averaged information from that cell. It will be of interest to also record data in a mode such that spatial dependencies may be determined for signals coming from several contiguous range cells. Therefore, a second operating mode will include recording sampled radar video signals from three contiguous range cells for the parallel-polarization channel only for all four radar systems.

Multipath interference effects will be documented using a corner reflector mounted on a helicopter flying prescribed paths toward the radar systems. Table 12 lists the matrix of environmental, geometric, and radar parameters which will form the basis of this data collection task. Three sea states are desired for comparison of effects. Helicopter altitudes of 10, 20, and 30 meters will be maintained over a radial flight path toward the radars from a maximum range of 12 kilometers (1° to the sea) to a minimum range of .3 kilometers (3° to the sea). All four radar systems will be used, with manual tracking of the helicopter over the entire range swath. Both horizontal and vertical polarizations will be utilized, with the parallel receiver channel sampled for recording.

Propagation measurements will utilize a corner reflector or plate mounted on the nearest shore-based tower. Received power will be monitored and recorded from before sun-up to after sundown for all four frequencies on a day when ducting can be anticipated. Both polarizations will be used on transmission, while both are received simultaneously.

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Table 12

MULTIPATH INTERFERENCE MEASUREMENT MATRIX

Environmental Parameters

    Sea State   1, 2, 3

Geometric Parameters

    Helicopter Flightpath   Altitude: 10, 20, 30 meters
                                          Orientation: radial
                                          Range: 12 to .3 kilometers

Radar Parameters

    Frequency   9.5, 16, 35, 95 GHz

    Polarization   Horizontal and Vertical

For the sea backscatter measurements a calibration target is absolutely essential. This calibration will be effected by mounting a flat plat rigidly on a shore-based tower approximately 4 kilometers from the Stage II Tower. Orientation of a square plate in a diamond configuration creates a backscatter pattern with extremely low sidelobe levels when illuminated uniformly by either horizontally or vertically polarized signals. Low sidelobes will decrease drastically any multipath effects incurred when calibrating with the received energy at the radar systems from this plate.

Prior to a day's data collection, each of the four radar systems will be calibrated using the flat plate reflector mounted on a shore-based tower. Assuming that the calibration levels are nominally close to calculated levels (established with a signal generator, system parameters, and the radar equation), data collection will be initiated. Video signals from the radar systems will be sampled for recording on 14-track FM tape, which will also contain the calibration signals.

The four radar antennas will be manually set to a designated elevation and azimuth orientation so that all four radar systems are illuminating the same sea sector. Range gates for the samplers for all video signals will then be set so that all samplers are on the same range cell on the sea surface. For the multi-range cell measurements, equivalent pairs of range gates would be aligned, using an oscilloscope and time measurement from transmit. After a period of recording of several minutes, all four antennas would then be repositioned to a new depression angle, and the procedure would be repeated until all angles in the next matrix had been covered.

This general procedure will then be repeated for a new heading into the wind/wave direction according to parameters listed in the test matrix. The order in

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which these headings will be effected obviously will depend on the prevailing weather conditions and sea state conditions.

For the multipath interference measurements, a precalibration procedure as previously described will be used before actual data collection is begun. A sufficiently large trihedral corner reflector will be mounted in, or on, a helicopter flying radial flight profiles toward the radars on Stage II at a reasonably constant speed of about 10 meters/second, which should result in about 19-½ minutes' data per pass. Angle tracking by the radar antenas will be accomplished manually, as will range tracking, using an oscilloscope as an A-scope presentation.

The propagation measurements will be accomplished by boresighting all antennas onto a corner reflector mounted on one of the shore-based towers the day before. Before daybreak the radar systems will be turned on, and the range gates all set at the range of the reflector. Received signals will be recorded on FM tape for several minutes at a time, at hour intervals, until after sunset. During the daytime a calibration will be made on a flat plate mounted on the same tower.

The calibration procedures to be used during the measurements are intended to complement and, indeed, add an essential degree of confidence to the system calibration performed prior to the field exercise. This previous procedure will consist of determining, for each radar system, its transmitted power level, pulse-length, system losses (primarily waveguide losses), and a system transfer function relating power received at the antenna ports to video signal levels out of the detector/amplifiers. This determination permits calculation of video signal level for a given target at a specified range using the standard range equation with appropriate factors.

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This bench calibration utilizes a signal generator and calibrated antenuator to inject a signal into the radar system of specified level, i.e., so many milliwatts (dBm). A power meter is then used to measure the rf power at the other end of the waveguide run and attendant components. The difference in power between these two points in decibels thus represents the system loss for this set of components. The transmitted power is measured simply by connecting the power meter to the output leg via a directional coupler and attenuator to protect the power meter. A system transfer curve can be determined by injecting a calibrated signal into some point of the system at rf for which the relative loss values have been determined and recording the corresponding video output level, for a set input signals which correspond to the entire dynamic range of the receiver. This procedure is repeated for each polarization channel of each system. Obviously, this bench calibration procedure can be effected only when signal sources and power meters are available and when coupling into the system at rf is possible.

Calibration from Stage II then consists of recording on FM tape and strip chart the sampled video signal which results from illuminating a flat plate reflector mounted on one of the towers on the shoreline some three kilometers away. If the video signal level recording is close to the calculated value from the range equation and the system transfer function previously determined, the calibration process is considered "closed."

For those systems where a bench calibration is either not possible or not feasible, a system tranfer curve can be generated from Stage II by the above procedure using a calibrated set of attenuators in each receiver line, preferably at rf. The signal reflected off the flat plate then becomes the signal source and may be related to square meters since the radar cross section of the plate is known.

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However, note that using the Tower calibration procedure alone does not assure the identification of anomolous propagation conditions, since they will manifest themselves as an overall signal loss factor.

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